Beach Sand Seismoacoustics

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LONG-TERM GOALS

The goal of the research is to develop fundamental physical understanding of the seismoacoustic properties of unconsolidated marine sediments under various conditions. The research outcome would lead to a) accurate modeling and prediction of the interaction of high-frequency underwater acoustic waves with water covered marine sediments, and b) reliable seismoacoustic detection of buried objects both in shallow water and near the beach where the acoustic properties of nonuniform drying of sand with salt, trapped air bubbles, biological traces, and inhomogeneities are least understood.

OBJECTIVES

Investigate grain to grain high-frequency seismoacoustic coupling mechanisms and effective shear rigidity of compacted sediments stemming from micromechanisms controlled by water content, salt, grain shape, grain size, roughness, compactness, microbubbles, water impurities, capillarity, and heterogeneous nucleation at sand grain interfaces.

APPROACH

Focus on phenomena not previously investigated and help resolve outstanding controversial problems on high-frequency seismoacoustic properties of beach sand under various conditions. Use ultrasonic techniques developed by the author [1-10] since 1979 to obtain qualitative and quantitative experimental results under controlled laboratory conditions. Various types of ultrasonic modeling materials are used to identify, isolate, and charaterize different acoustic coupling mechanisms. Conduct experiments on sand, spherical glass beads, and glass plates. A broadband ultrasonic pulse is transmitted in the models (bulk sand, single grain, parallel glass plates, ...). The received signal is analyzed to provide the desired measured acoustic properties (velocity, attenuation, dispersion, ...). Enhanced ultrasonic modeling is used as needed to increase the signal level of a specific mechanism under study. Depend on extensive ultrasonic modeling expertize to conduct cost-effective precision experiments with reliable repeatable results.

WORK COMPLETED

The research focused primarily on the effect of moisture content on high-frequency compressional wave velocity in drained sand. Measured the compressional wave velocity as function of water content in spherical glass beads and in coarse, medium, and fine sand (Fig. 1) [8-10]. Carried out studies on the effect of salinity on grain to grain acoustic coupling (Fig. 2-3) [10]. Characterized compressional and shear waves in beach sand with evaporated seawater forming a sand/salt crust (Fig.

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14. ABSTRACT
The goal of the research is to develop fundamental physical understanding of the seismoacoustic properties of unconsolidated marine sediments under various conditions. The research outcome would lead to a) accurate modeling and prediction of the interaction of high-frequency underwater acoustic waves with water covered marine sediments, and b) reliable seismoacoustic detection of buried objects both in shallow water and near the beach where the acoustic properties of nonuniform drying of sand with salt, trapped air bubbles, biological traces, and inhomogeneities are least understood.

15. SUBJECT TERMS

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4) [10]. Obtained preliminary results from glass plates indicating the potential existence of a "suction-cup" effect between compressed sand grains strongly coupling shear waves in the absence of roughness (Fig.5) [11].

RESULTS

Several fundamental controversial problems are still unresolved regarding the seismoacoustic response and acoustic properties of seawater-saturated sand [12-14], moist sand [15-17], and dry beach sand [15-16]. The value of the sand frame bulk modulus given by Chotiros [13] is more than 10x greater than the known value. The bulk modulus of sand grains given by Chotiros is 5x smaller than the known value. The compressional wave velocity in typical water-saturated sand is near 1700 m/s which is about 8x greater than in dry sand. Results by Velea [16] and Tavossi and Tittman [17] near 10 KHz revealed that the compressional wave velocity in drained sand in about 200 m/s.

The author [8-10] demonstrated experimentally that the velocity of high-frequency (~100 KHz) compressional waves in water-saturated sand remained near 1700 m/s when the sand was drained and did not decrease by a factor of eight. The compressional wave velocity actually slightly increased by about 9% as the water saturation was decreased from 100% to 82% as shown in Fig. 1. Results from spherical glass beads, coarse sand, medium sand, and fine sand are compared. The increase in compressional wave velocity was greater for the uniform glass beads than for the fine sand. Bachrach and Nur [9] calculated the compressional wave velocity as function of water saturation in sand based on the Biot-Gassmann prediction. The calculated results show that starting with dry sand, the compressional wave velocity initially decreases as the water content is increased, and then the velocity starts to increase above 85% water saturation. At 99% water saturation, the compressional wave velocity is still less than 200 m/s. According to the theoretical model, the last 1% of water saturation increases the compressional velocity by almost a factor of eight.

The effect of salinity on grain to grain acoustic coupling is shown in Fig. 3. The transmission of a compressional wave pulse across dry contact coupling is shown in the top trace of Fig. 3. Distilled water coupling produced a large transmitted compressional wave (second trace from the top). When the distilled water was evaporated, the signal level dropped and returned to the previous dry contact condition. Replacing the distilled water with seawater (salinity 3.5%) produced substantially different results as shown in Fig. 3. The evaporation of seawater formed salt crystals creating a solid mechanical bond allowing the transmission of compressional waves. The bottom two traces were obtained using seawater that was diluted (salinity 1.25% and 0.625%). As the salinity was decreased, the amplitude of the transmitted compressional wave decreased. Ultrasonic studies on single sand grains were conducted as shown in Fig. 2. Ultrasonic waves were guided in a fine copper wire epoxied to one side of a sand grain.

Beach sand contains salt from evaporated seawater and under certain conditions may form a porous solid sand/salt crust. The presence of salt can increase the compressional wave velocity from 200 m/s to 2887 m/s as shown in Fig. 4. The shear wave velocity also increased from near 10 m/s to 1885 m/s. A brief rain can transport the salt from the beach surface to deeper sand resulting in large variations of sand acoustic properties. Salt crystals have acoustic properties close to sand grains (compressional wave velocity 4.53 km/s, and density 2.165×10^3 kg/m^3) and can create a significant mechanical bond between sand grains.

In partially saturated sand, capillary forces are present. The thin water film existing between sand grains has a dramatic effect on the acoustic properties of sand. The author hypothesized that in addition to the capillary forces, there may be another force due to the suction-cup effect between sand grains under certain conditions. A preliminary experiment was conducted using two smooth microscope glass slides and a thin capillary water film between them. Fig. 5 shows negligible shear coupling between the glass plates in the absence of the suction-cup effect (bottom trace). When the two glass plates were pressed against each other, cavitation microbubbles developed as the tensile strength of the thin capillary water film was exceeded resulting in a negative pressure and a suction-cup effect strongly bonding the two glass plates preventing them from sliding. Substantial shear waves were coupled between the two glass plates when the suction-cup effect was present. The glass plates remained stuck together when the applied force was removed. The theory of elastic waves in unconsolidated sediments by Buckingham [14] depends on grain roughness, where the shear speed goes to zero as the losses vanish. The preliminary results [11] indicate that in the absence of roughness, a very large rigidity modulus and shear coupling can be created when two smooth solids separated by a capillary thin water film are pressed against each other, due to the formation of cavitation microbubbles and a "suction-cup" effect. Future work will assess the potential seismoacoustic role of the "suction-cup" effect in compacted sediments.

IMPACT/APPLICATIONS

Develop better physical understanding of seismoacoustic phenomena on the interaction of underwater acoustic waves with marine sediments leading to accurate acoustic modeling of littoral surficial layer and reliable seismoacoustic detection of buried objects in shallow water and on the beach.

TRANSITIONS

The research outcome provides basic physical understanding needed to develop theoretical models for predicting the acoustic properties of seabed leading to accurate ocean bottom characterization and reliable high-frequency seismoacoustic detection of buried objects in saturated, moist, and dry marine sediments.

RELATED PROJECTS

The work relates to several sponsored ONR research projects on marine sediment modeling and characterization, high-frequency sound interaction, seismic sonar, surfseisms, air bubbles in sediments, and marine biology (N. P. Chotiros, R. D. Stoll, E. I. Thorsos, D. R. Jackson, A. N. Ivakin, K. Williams, H. Simpson, M. Richardson, R. Stoll, M. Buckingham, T. Muir, E. Smith, J. Lopes, G. D'Spain, D. Bibee, D. Velea, J. M. Sabatier, D. H. Berman, G. B. Deane, V. Holliday, P. Jumars, R. Lim, R. A. Stephen, and P. Kackzkowski).

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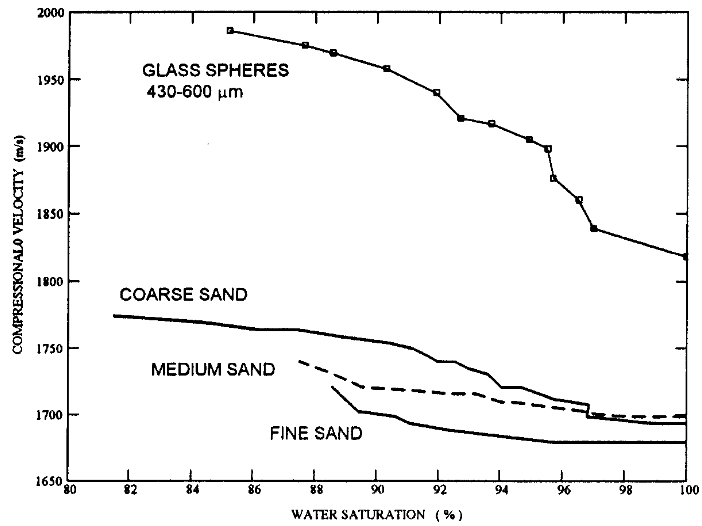


Fig. 1. Measured compressional wave velocity as function of water saturation [10].

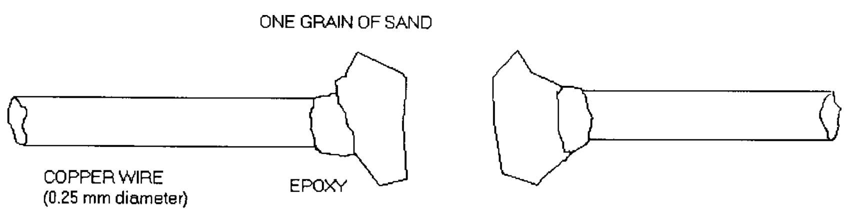


Fig. 2. Ultrasonic waves coupled to one grain of sand.

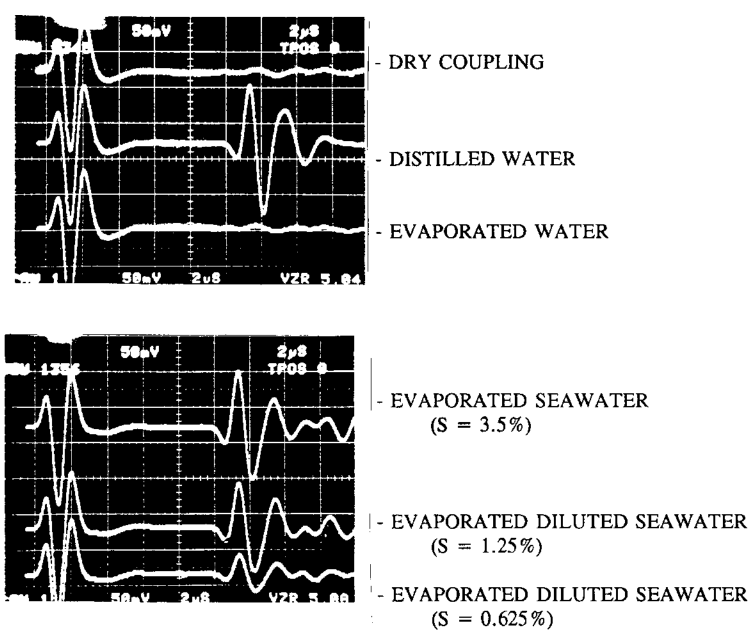
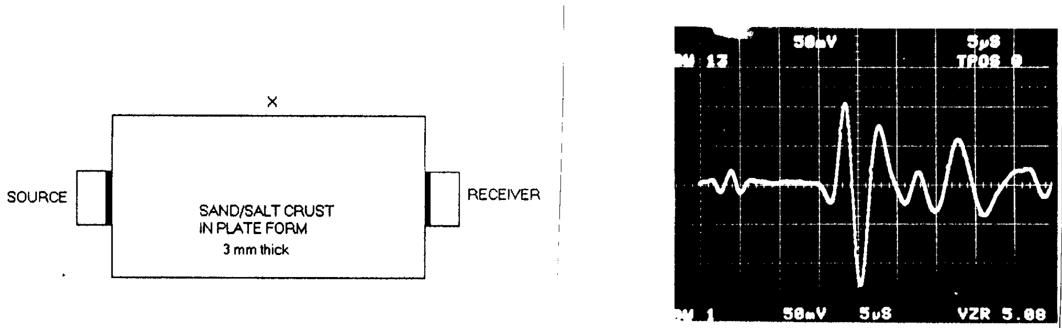


Fig. 3. Effect of salinity on grain to grain contact acoustic coupling of compressional waves [10].



X = 4.2 cm
C_p = 2887 m/s
C_s = 1885 m/s
SAMPLE #1

Fig. 4 . Compressional wave in dry beach sand/salt crust following seawater evaporation. Salt crystals bonding the sand grains increased the compressional wave velocity by a factor of ten [10].

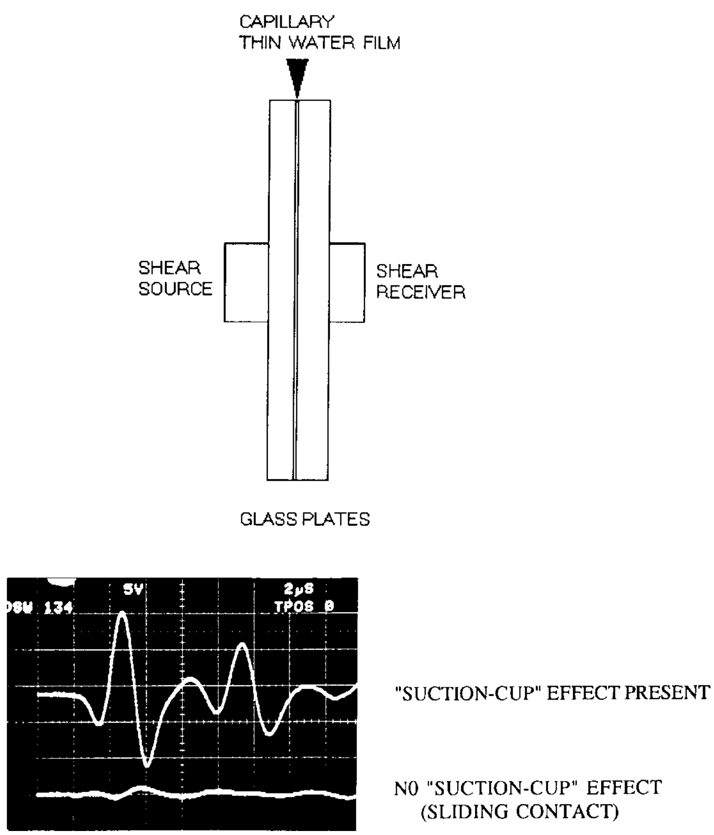


Fig. 5. Basic experiment demonstrating shear wave coupling between two smooth glass plates when "suction-cup" effect is present. When the two glass plates are pressed against each other, cavitation microbbles are formed as the tensile strength of the thin capillary water film is exceeded resulting in a "suction-cup" effect strongly bonding the two plates preventing them from sliding. Newton fringes could be observed at localized spots on the plates [11].